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The "Large Helical Device (LHD)" project will start the plasma discharge experiments in March 1998, and its data acquisition system is expected to take 600 $\sim$ 900 MB of diagnostic data by a 10-seconds short-pulse discharge experiment. The steady-state operation of about 1-hour discharge duration will be also planned in the following experimental periods, where the total amount of acquired data will be enlarged.

These huge amount of experimental data enforces us to adopt the fully distributed data acquisition and processing system, rather than the usual concentrated one which often uses the mainframe. Necessary conditions toward the LHD data processing system are to complete to acquire and process whole diagnostic data within 100 seconds after every discharge end.

The main idea of applying the distributed structure is to improve the data throughputs by using multiple transfer paths, at first. Modern technologies of high-performance personal computers (PC), whose capacity have already catched up with engineering workstations (EWS), are also quite suitable for distributed and parallel data processing system, because their cheaper cost enables us to apply more cpu and machines.

In addition to the parallel distribution, the functional separation will be also effective to provide the advanced graphical user interface (GUI). The computer loads of the data visualization and complicated analysis are often unrelated to the data processing sequence following after a discharge experiment. Popular 2-dimensional or 3-dimensional analysis and visualization make heavy cpu loads, and a private cpu for each user will become more desirable. As a good solution of this problem, the network client–server model can be preferablly applied between data acquiring and storing servers and user-interfacing clients.

The distributed model is applied both in parallel and functional meaning for LHD. It has two kinds of server computers; One kind is the data acquiring and storing computers which govern the CAMAC digitizers and databases, the other is the diagnostics controlling computers which interactively manage and continuously monitor the diagnostic devices in real-time. The former applies so-called AT-compatible PC and WindowsNT OS, the latter does 68040-based VME and real-time OS Tornado. Both kinds of server computers will be prepared independently for each diagnostics of 20 or 30 kinds. As for the connections between many server and client computers, 100 Mbps FDDI-based switching network has been applied for fast data transfer.

LHD data processing system apples above-mensioned new technologies and is being developed now.

Keywords:

LHD, distributed system, data acquisition, diagnostics control, VME, WindowsNT

DISTRIBUTED PROCESSING AND NETWORK OF DATA ACQUISITION AND DIAGNOSTICS CONTROL FOR LARGE HELICAL DEVICE (LHD)

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ABSTRACT. The LHD (Large Helical Device) data processing system has been designed in order to deal with the huge amount of diagnostics data of 600~900 MB per 10-second short-pulse experiment. It prepares the first plasma experiment in March 1998. The recent increase of the data volume obliged to adopt the fully distributed system structure which uses multiple data transfer paths in parallel and separates all of the computer functions into clients and servers. The fundamental element installed for every diagnostic device consists of two kinds of server computers; the data acquisition PC/Windows NT and the real-time diagnostics control VME/VxWorks. To cope with diversified kinds of both device control channels and diagnostics data, the object-oriented method are utilized wholly for the development of this system. It not only reduces the development burden, but also widen the software portability and flexibility. 100Mbps FDDI-based fast networks will re-integrate the distributed server computers so that they can behave as one virtual macro-machine for users. Network methods applied for the LHD data processing system are completely based on the TCP/IP internet technology, and it provides the same accessibility to the remote collaborators as local participants can operate.

1. INTRODUCTION

The "Large Helical Device (LHD)" project will start the plasma discharge experiments in March 1998, and it is one of the world largest helical plasma experimental device often compared with the Wendelstein 7-X in Germany [1].

Three world largest tokamak device of JET, JT-60 and TFTR were constructed in 1980s, and in the following ten years technological surroundings around the data processing system had been quite improved especially in the aspects of the semiconductors and networks. The progress of the semiconductor technology comes to not only the computer memories but also the diagnostic sensors like the multi-dimensional CCD (Charge Coupled Device). Larger capacity of computer memory and more precise sensors keep on increasing both the volume and variety of plasma diagnostics data.

The LHD data acquisition and management system is expected to take 600 ~ 900 MB of diagnostic data by a 10-second short-pulse discharge experiment. In addition, the steady-state operations of about 1-hour discharge duration will be also planned in the following experimental periods, because LHD applies the superconducting magnets to all of the helical, poloidal and vertical field coils. The total amount of acquired data will be certainly enlarged due to the long duration. These huge amount of experimental data enforces us to adopt the fully distributed data acquisition and processing system, rather than the ordinary concentrated one which often uses a supercomputer called mainframe. Necessary conditions toward the LHD data processing system are to complete to acquire and process whole diagnostic data within 100 seconds after every discharge end. In order to satisfy them, the LHD data acquisition system was obliged to utilize the parallel tasking structure and reduce the data processing load of the individual element, such as data I/O ports or cpus.

The principles for the new LHD data acquisition and management system are as follows [2];

1. complete parallel distribution for each diagnostics device
2. functional separation using network client/server model
3. 100Mbps FDDI-based fast switching network
4. object-oriented method as programming manner
5. commercial-based distributed database .

The first objective to apply the distributed structure is to improve the data transfer throughput by using multiple paths and cpus. The more splitted number brings the shorter time spent in data transfer and processing. Modern technologies of high-performance personal computers (PC), whose capability become comparable with engineering workstations (EWS), are also quite suitable for distributed and parallel data processing system, because their cheaper cost enables to introduce more cpus and machines.

In addition to the parallel distribution, the functional separation will be also effective to provide the advanced graphical user interface (GUI). The computer loads of the data visualization and complicated analysis are often unrelated to the data processing sequence following after a discharge experiment. Popular 2-dimensional or 3-dimensional analysis and visualization make heavy cpu loads, and a private cpu for each user will become more desirable. As a good solution of this problem, the network client/server model can be preferably applied between data acquiring and storing servers and user-interfacing clients.

Fast network connections are indispensable for the mutual data transfer between those separately arranged computers. Especially among the data acquisition server computers, the fast mutual linkage and close concurrent cooperation could materialize a virtual macro-machine, which the client computers can send requests to and receive answers from. In other words, this virtual machine uses fast network links as its internal system bus. They exactly organize a massive parallel-tasking multi-processor system with loosely-tied communications [3].

The distributed structure is applied both in parallel and functional way for LHD data processing servers. It utilizes two kinds of server computers shown as Fig. 1; One kind is the data acquiring and storing computers which govern the CAMAC digitizers and databases, the other is the diagnostics controlling computers which interactively manage and continuously monitor the diagnostic devices in real-time. The former uses so-called AT-compatible PC and Windows NT OS, the latter does 68040-based VME and real-time OS Tornado, which is previously known as VxWorks. Both kinds of server computers will be independently stationed for every diagnostics of 20 or 30 kinds.

In the following sections we mention about the parallel distribution and functional separation at first, and afterwards it will be described how we organize the relationship among lots of computers. Our attempts of LHD remote collaborations by means of FECnet (Fusion Experiments Collaboration network) in Japan are also explained at last.

2. DATA ACQUISITION

In this section, the data acquisition system for the measurements of physical analysis which generally requires so fast data sampling as to follow the plasma intrinsic frequencies of dynamic behaviors. They manages the CAMAC digitizers and transfer, transform and store the experimental data, where all of the processing sequences are executed in the pre- and post-experimental periods as they were preprogrammed. These flow of the data treatment are often recognized as so-called the batch processing.

Sub-components of the LHD data acquisition can be classified into the categories as listed below,

1. digitizing by CAMAC modules
2. SCSI data transfer with optical extender
3. PC/Windows NT data acquisition server computers

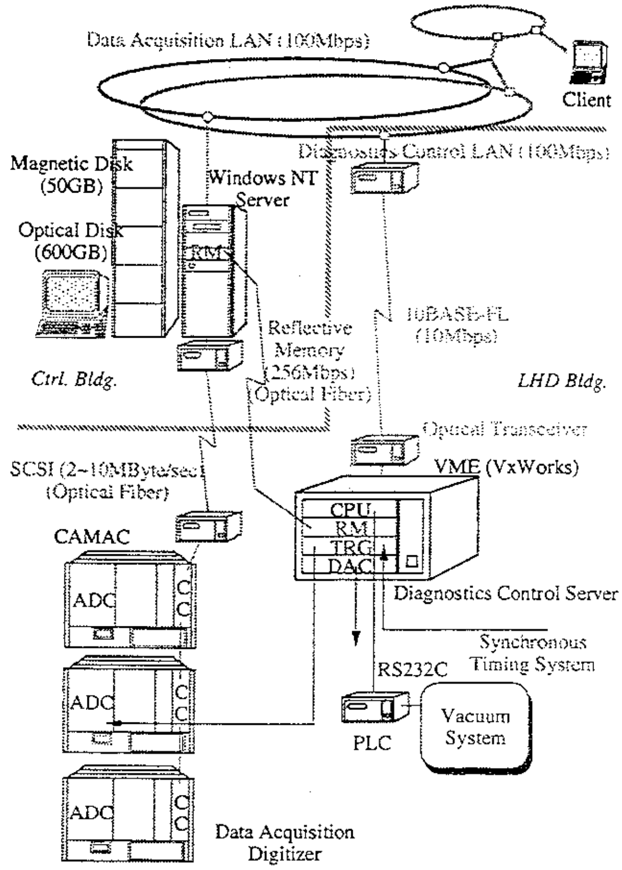

FIG. 1. A basic element of the CAMAC data acquisition and VME device control/monitor system: This set will be applied for each kind of the LHD diagnostics device.

4. data cross-referencing by virtual shared memory
5. object-oriented database on every server computer
6. harddisk array and media-changeable mass-storage

As for the digitizer modules for LHD, we have to inherit a lot of CAMAC properties which had been working in the prior experimental devices, namely, JIPP T-IIU and CHS.

JIPP T-IIU and CHS data acquisition systems [4] are based on the VAX/VMS computers which manage all the CAMAC crates through the ordinary CAMAC highway driver. They applies the so-called concentrated system structures and whole experimental data goes through the highway driver, where the data transfer throughput suffers from the bottleneck of the I/O concentration. It often causes the delay of the 5-minute periodical discharges because it requires longer time to complete the data transfer.

The LHD diagnostics plans to acquire a few ten times multiplied mass volume of experimental data compared with above mentioned two devices. Thus, the huge volume of the LHD diagnostic data forced inevitably to adopt the multiple data transfer paths and the distributed data processing computers. Considering the CAMAC dataway's capability of maximum transfer rate of 1Mword/s, splitted number of the data path will be expected to be a few ten. It is fortunately near the number of the diagnostics kinds in LHD.

Consequently, we adopted the distributed system for the LHD data acquisition and processing system by means of using about 30 sets of the IBM-PC compatible personal computer and Microsoft Windows NT operation system. The most popular and reliable PC interface for the peripheral devices is well known as SCSI, and it performs enough high data transfer rate for connecting the CAMAC crate controllers to PCs with a reasonably low cost. Modern SCSI controllers for usual PCs provides the ideal transfer rate up to 20MB/s. Another advantage of adopting the PC and SCSI is that they have the widest compatibility and are easy to extend the components of the system. Figure 1 shows an elementary set of the data acquisition and diagnostics control system and Fig. 2 shows the schematic view of the relationship among the sub-clusters of the LHD experiment network.

Windows NT has the same mechanism of the multitask, the multithread, the multiuser handling and others quite similarly as the VAX/VMS system does [5]. In addition to them, it provides the "Win32" graphical API (Application Program Interface) [6], which serves the comfortable and stable environment for the system coordinator and programmers to make the cooperative network programs. Lots of commercial softwares for Win32 also promote them.

As for the data storage and retrieving, we applied the hierarchical storage systems (HSM) of two classes due to their storing terms and read/write speed performances. One is the high-speed short-term storage of relatively small volume, and the other is the long-term storage which has a mechanism of the media auto-changer. For the LHD data acquisition system, we prepared 30 sets of the 50GB RAID (Redundant Array of Independent Disks) and a few sets of magneto-optical (MO) jukebox whose maximum capacity is up to 600GB. Particularly for the long-term storage, the new technology of the DVD (Digital Versatile Disk) will become preferable in the near future because it is the randomly accessible media like CDROM and also has the recordable or rewritable DVD-R/DVD-RAM specification of about 4.6 GB within the same size of 12cm CDROM. DVD is more compact and has larger capacity than MO, and especially the auto-changer will be quite smaller and cheaper than the present MO jukebox.

In order to use these two classes of storage systems translucently and reduce their administrative human cost, a kind of the HSM commercial software on Windows NT has been introduced. It manages the virtual volume on the multiple MO media in the jukebox and the cache information on RAID, and coordinates them into a virtual storage volume which users do not have to administrate manually.

3. DIAGNOSTICS CONTROL

The LHD device control systems have three sub-clusters of the experimental control, the torus control, and the diagnostics control. The first manages plasma heating devices, the power supply system, and cryogenic equipments. The second controls the vacuum vessel and plasma itself, and the last operates every diagnostics device.

The diagnostics control system has a simple tree-structure. Almost all of the diagnostics control systems are installed for individual diagnostics and independently do the management for each device. Only one central status manager has a connection with the LHD central operation/control system, and it distribute or integrate the interlocking signals and the timing trigger signal from/to the distributed control systems.

As far as the diagnostics control system is concerned, the data amount of the device control or monitoring is not so large, and thus the parallel data paths are not necessarily indispensable for the wide transfer bandwidth. The large number of control or monitoring I/O channels, however, requires the distributed management computers. It is mainly because the device control and monitoring generally requires the real-time processing, and the interrupts handling capability of most computer processors is generally less than about 1k interrupt per second regardless of its kind. As a result, we decided that both the data acquisition computers and diagnostics control ones should be installed respectively for every diagnostics in LHD.

As the diagnostics management computer, we adopted the VME system and the real-time OS Tornado, previously known as VxWorks. VME module products have much variety, and for a typical set we applied the Motorola 68040-based cpu module, A-D/D-A converters, isolated or non-isolated digital I/O modules, and communication port like RS-232C and GP-IB. Required functions for them are as follows;

1. real-time remote manipulation of active equipments
2. real-time status monitoring
3. timing trigger system management
4. hardware interlocking surveillance.

Particularly for LHD, its superconducting coils generate the steady DC magnetic field during the experimental term, for instance, a whole day. it prevents people to access the diagnostics equipments directly, and as a result, the device controlling and monitoring server computer with no magnetic harddisks becomes indispensable. The timing trigger

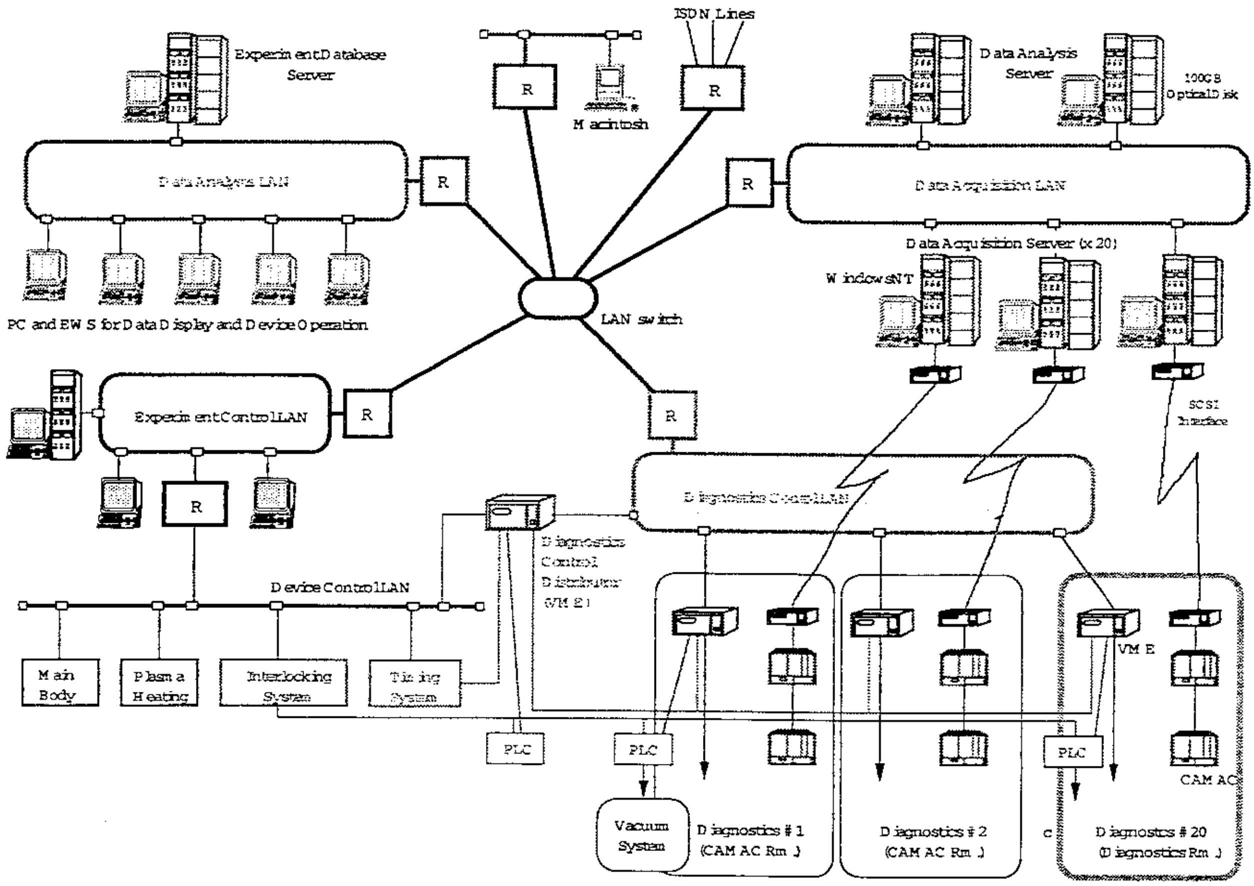

FIG. 2. Schematic view of the relationship among the sub-clusters of the LHD experiment network: They are categorized into three part of (1) the experiment/torus/device control, (2) the data acquisition/diagnostics control, and (3) the experimental analysis sub-clusters. All of the clients which accesses the (2) servers exist in (3).

system which is important both for the diagnostics control and the data acquisition digitizers is another objective for the real-time control.

The hardware interlocking system generally requires more protected direct linkages which organize the simple logic for the device safety against the human operation errors. They are usually made by the state-held wired logics and the electric relay switches. The PLC (Programmable Logic Controller) is the solid-state modular substitute for the relay circuits. It is computer controllable through the communication port like RS-232C, and the internal logical circuit can be printed by the offline downloading program into the inner flash memory. For easy programming of PLC logics for the individual diagnostics users, we have developed a new Win32 GUI downloading program for the OMRON C200HS PLCs which will be used in the LHD diagnostics interlocking system. Those PLCs, as a whole, will cooperate with the central interlocking system in protecting the individual diagnostic hardwares and other systems.

The cooperation and the protective data transfer between the PC and VME computers are established through the reflective memory system which has been newly developed in order to reflect one's memory image onto the other's. Thus, the two different kinds of server computers of PC and VME are linked by the different bus-interfaced reflective memory boards of PCI-bus and VMEbus.

4. NETWORK COMMUNICATION

As mentioned in previous sections, a distributed system certainly requires some re-integration mechanism so that every distributed element could work in coordination with others. Especially for the LHD data acquisition system, fast network connections are indispensable for the mutual data transfer among distributed server computers because they have to treat the huge amount of experimental raw and calculated data.

The ordinary fusion plasma experiments have the general tendency that experimental data transfers concentrated into only a definite time after the discharge, where the maximum transfer rate are surely expected. Such characteristic is quite suitable to apply the impermanent point-to-point connection by means of a momentary circuit-switching technology. Modern network equipments applies various kinds of fast network standards, namely, Fast-Ethernet, Gigabit-Ethernet, FDDI, and ATM, and all of them have the extension to the switching facility. As the fast switching network, we have adopted the 100Mbps FDDI-based switching equipments as the local connections for end computers, and as a backbone of the data acquisition network, applied a 622Mbps ATM.

As for the diagnostics control VME computers, they do not have to deal with a large volume of data and thus 10Mbps Ethernet connections provide enough bandwidth between VME servers and client machines. The more controlling channels the VME computer have to manage, however, the heavier load the network cpu takes. Once the packet congestion occurs, the traditional Ethernet by the collision detection mechanism will cause much heavier cpu loads and obstruct the real-time processing. As a result, a point-to-point connected collision-free switching network is desirable even for the real-time diagnostics control computers. For this purpose we have adopted the switching fiber-linked Ethernet (10BASE-FL) ports which also provide the electric insulation by means of optical fibers.

Networking methods applied for the LHD data processing system are completely based on the TCP/IP internet technology.

For the interactive communications between the diagnostics control VME computers and their remote operation terminals, the remote procedure call (RPC) package of the ONC RPC 4.0 has been applied [7]. It provides the advanced function calls both for the server and client programs by using the enclosed automatic rpc-generator tool. The RPC itself is classified into the upper protocol layer, namely, the presentation layer of the internet TCP or UDP transport layer, and it reduces the programmer's burden of directly managing the lower network layers by means of concealing them. For the remote operation of the diagnostics devices, the RPC protocols directly link the VME servers and clients. See Fig. 3. It realizes the real-time remote manipulation and monitoring which is the newly additional feature to the conventional data copy or transferring methods.

The virtual shared memory package of HARNESS [8] is another presentation protocol layer we have applied for the data acquisition and management system, as shown in Fig. 4. It provides the different kind of functions comparing to the RPC. RPC provides a simple mechanism of giving and receiving messages, while HARNESS makes the shared memory space among the invited participant computers where any kinds of experimental data objects can be

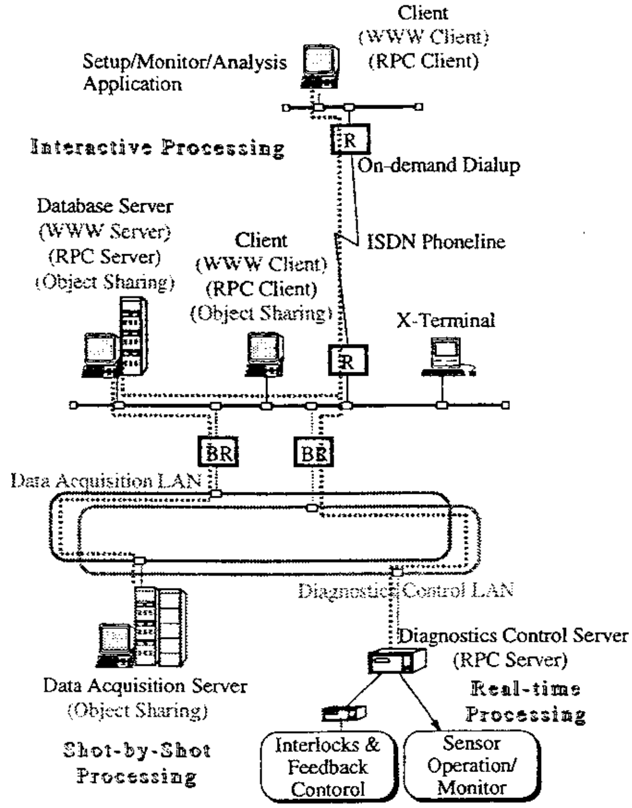

FIG. 3. Client/server behaviors through ISDN connection: Once the on-demand dial-up connection is established, there is no logical differences between local and remote clients. They all use the same accessing protocols to the PC and VME servers.

shared simultaneously.

As for the data retrieve, transfer, and store, remote and local clients can directly communicate with the experimental database servers. The LHD data acquisition system adopted the object-oriented databases due to the suitability for the object-oriented data handling manner which unifies the overall system construction. The communications between databases and clients are established by the standard script language for the object-oriented database, namely, the object query language (OQL). The OQL is one of the application script language which is independent of the network or transport protocols. Of course, it implies the OQL script can also be sent by the TCP/IP.

As precisely described in the nest section, both of RPC, HARNESS, or OQL which use the internet protocol (IP) as its basis can be available from anywhere on the internet. This is one of the best advantage of the LHD data processing system, and is also the reason why we could separated the client and server machines completely and fully introduced the internet communications between hardware devices and human users.

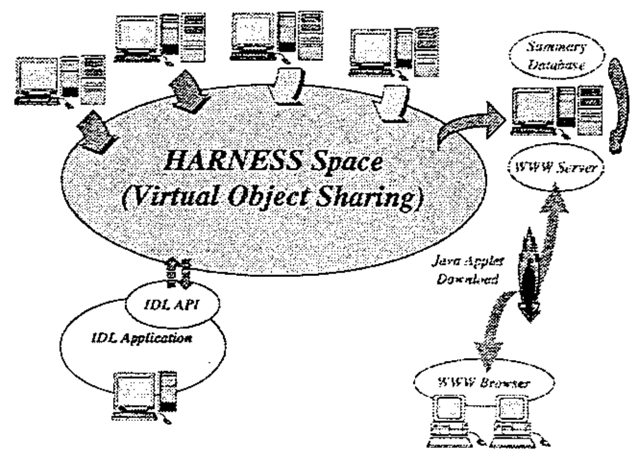

FIG. 4. Virtual shared memory system by HARNESS SPACE*:* HARNESS *provides the object sharing functions and the task processing synchronization due to the data object delivery.*

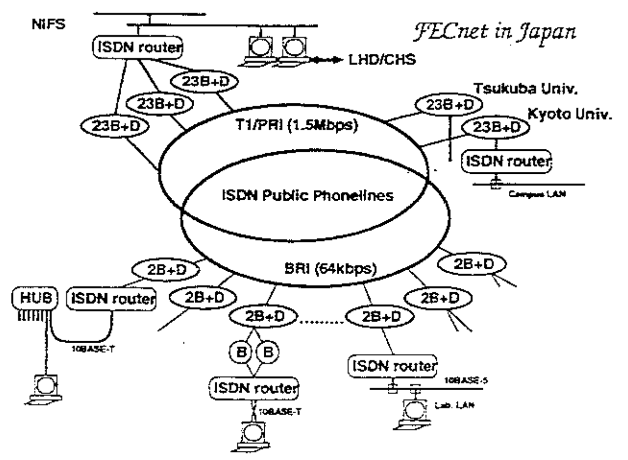

FIG. 5. Overview of the FECnet: It applies the NTT digital public lines named INS64 (2B+D) and INS1500 (23B+D) for on-demand dial-up point-to-point connections. The former is for laboratories and the latter is for research institutes. The difference between them, however, is just the maximum bandwidth.

5. REMOTE COLLABORATION

The research project of the collaboration network for the fusion plasma experimental researches invested for construction in 1995 Japanese FY. As a result of it, the fusion experiments collaboration network (FECnet) had started the operation as the Japanese inter-university collaboration network for fusion research. The schematic view of FECnet is shown in Fig. 5. The necessary conditions for the remote collaboration of fusion plasma experiments are considered to be as follows;

1. equivalent data accessibility, as the local data terminals
2. interactive device manipulation and monitoring
3. communication multi-media, for drawing up the next experiment.

In order to give the all-out support for them, the LHD data acquisition and diagnostics control system has adopted, from the first stage of its schematic design, the distributed network structure where the client and server computers are completely separated without any direct wire links. The overall c/s separation disregarding the difference of the remote and local site enables to provide the equivalent experimental environments to remote collaborators just as the local site.

The concrete method to do that is established only by the modern internet technology because it provides the distant telecommunication protocols and release us from the limitation of the connection length between devices and users. As Fig. 3 shows, both of the local data terminals and remote ones talk the same communication protocol or languages like RPC, OQL or HTML, and equivalently connect and access to the data acquisition, diagnostics control, experimental database servers. They make clear that the LHD data processing system has the ability to provides the same accessibility to the remote collaborators as local participants can operate.

In order to satisfy the last condition of the remote collaboration, the human communication mechanism for discussions of evaluating the last plasma discharge and drawing up the next experiment parameters will be certainly required between the local experiment coordinators and remote collaborators. The Cornell University/White Pine "CU-SeeMe" video phone or conference system is the popular solution which provides,

- TCP/IP multicast support for LAN/WAN conference
- H.323 (H.263) standards based video, T.120 whiteboard
- motion JPEG (M-JPEG) video over LANs and ISDN,

and so-called the reflector becomes the server component of client/server videoconferencing solution with them. Because their communications are wholly based on the IP protocols, it is quite easy to apply them to the LHD data processing LAN and WAN clients.

6. SUMMARY

The LHD data acquisition and diagnostics control system are designed to be fully distributed and functionally separated. They are now under construction for the first plasma experiment in March 1998.

One of the most significant advantage of this system seems to be that the maximum utilization of the popular and reliable hardwares like PCs, SCSI, and Ethernet reduces the cost of the system construction or modification well. In order that the LHD data processing system can deal with the large number of channels and huge volume of experimental data, fast switching network equipments based on the FDDI and ATM technologies have been introduced. The fundamental component of Fig. 1, however, has proved its ability to realize the high flexibility and scalability.

Another significant characteristics is that from the beginning of the system schematic design, all of managing programs has been completely based on the internet technology. It enables to wipe away the logical difference of the participation methods between the local and remote sites. Such condition shall be termed as "the open system" in exact meaning, which was expected as the key ideology to support the LHD remote collaboration experiments.

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